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Technology Evaluation Report

HYDROTECHNICS IN SITU FLOW SENSOR

National Risk Management Research Laboratory
Office of Research and Development
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NOTICE

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FOREWARD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of NRMRL's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

ABSTRACT

The U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program evaluated performance of HydroTechnics, Inc. flow sensors in measuring the three-dimensional flow pattern created by operation of the Wasatch Environmental, Inc. (WEI) groundwater circulation well (GCW). The GCW is a dual-screened, in-well air-stripping system designed to remove volatile organic compounds (VOC) from groundwater. Operation of the GCW creates a groundwater flow pattern that forms a three-dimensional regime known as a "circulation cell." EPA's evaluation of the GCW circulation cell involved use of in situ groundwater velocity flow sensors that were developed at Sandia National Laboratories and manufactured by HydroTechnics, Inc.

This Technology Evaluation Report (TER) documents and summarizes the findings of EPA's evaluation of HydroTechnics' flow sensors. The flow sensors are in situ instruments that use a thermal perturbation technique to directly measure the velocity of groundwater flow in unconsolidated, saturated, porous media. The manufacturer claims that the flow meter can measure horizontal and vertical flow rates and direction in the range is 0.01 to 2.0 feet per day (ft/day) (0.3 to 60.96 centimeter per second [cm/s]).

The GCW is a patented system manufactured by WEI and was demonstrated at Cape Canaveral Air Station (CCAS) by the U.S. Air Force Center for Environmental Excellence (AFCEE). AFCEE conducted a comprehensive evaluation of the GCW, including contaminant mass removal rates, groundwater dye tracer studies, and numerical modeling. Demonstration data collected by AFCEE are documented separately in "Groundwater Circulation Well Technology Evaluation at Facility 1381, Cape Canaveral Air Station, Florida Technology Summary Report" (Parsons 2001).

The primary conclusions of EPA's evaluation of the HydroTechnics flow sensors include:

- During GCW operation, the groundwater velocities measured by all seven sensors increased by more than 0.1 ft/day, indicating that (1) the sensors were within the circulation cell established by the GCW, and (2) the horizontal extent of groundwater circulation was greater than 15 feet. Flow direction data further support the establishment of a circulation cell and that all the flow sensors are within the horizontal extent of groundwater circulation cell.

- The demonstration data suggest that the flow sensors are responsive to changes in groundwater flow conditions and can be used to help define and evaluate the three-dimensional flow patterns.

This report is available from www.epa.go/ORD/SITE/reports.html. Printed copies can be obtained from National Service Center for Environmental Publications in Cincinnati, Ohio, at (800) 490-9198.

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

FIGURES

FIGURES (continued)

Figure

FIGURES (continued)

FIGURES (continued)

Figure

FIGURES (continued)

Figure

FIGURES (continued)

TABLES

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AFCEE	Air Force Center for Environmental Excellence
bgs	Below ground surface
°C	Degrees Celsius
CCAS	Cape Canaveral Air Station
cm/s	Centimeters per second
DC	Direct current
DCE	Dichloroethene
DFT	Dipole flow test
EPA	U. S. Environmental Protection Agency
ft/day	Feet per day
GCW	Groundwater circulation well
gpm	Gallons per minute
HP	Horsepower
KSC	John F. Kennedy Space Center
msl	Mean sea level
NAPL	Nonaqueous phase liquids
NRMRL	National Risk Management Research Laboratory
ORD	Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
Parsons	Parsons Engineering Science, Inc.
psi	Pounds per square inch
PVC	Polyvinyl chloride
QA	Quality assurance
QAPP	Quality Assurance Project Plan
QC	Quality control
RPD	Relative percent difference
SARA	Superfund Amendments and Reauthorization Act
SITE	Superfund Innovative Technology Evaluation
TCE	Trichloroethene
TEP	Technology Evaluation Plan
TER	Technology evaluation report
Tetra Tech	Tetra Tech EM Inc.
VOC	Volatile organic compound
WEI	Wasatch Environmental, Inc.
µg/L	Micrograms per liter

CONVERSION FACTORS

	To Convert From:	*To:*	*Multiply By:*
Length:	inch	centimeter	2.54
	foot	meter	0.305
	mile	kilometer	1.61
Area:	square foot	square meter	0.0929
	acre	square meter	4,047
Volume:	gallon	liter	3.78
	cubic foot	cubic meter	0.0283
	cubic foot	gallon	7.48
	cubic foot	cubic centimeter	28,317
Mass:	pound	kilogram	0.454
Temperature:	(°Fahrenheit - 32)	°Celsius	0.556
Time	days	minutes	1440

ACKNOWLEDGEMENTS

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The groundwater circulation well demonstration was a cooperative effort that involved the following personnel from the EPA Site Program and the U.S. Air Force Center for Environmental Excellence (AFCEE)

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Mr. John Hicks	Parsons Engineering, Project Manager
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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program evaluated performance of HydroTechnics, Inc. flow sensors in measuring the three-dimensional flow pattern created by operation of the Wasatch Environmental, Inc. (WEI) groundwater circulation well (GCW). The GCW is a dual-screened, in-well air-stripping system designed to remove volatile organic compounds (VOC) from groundwater. Operation of the GCW creates a groundwater flow pattern that forms a three-dimensional regime known as a "circulation cell." EPA's evaluation of the GCW circulation cell involved use of in situ groundwater velocity flow sensors that were developed at Sandia National Laboratories and manufactured by HydroTechnics, Inc.

The HydroTechnics flow sensors are in situ instruments that use a thermal perturbation technique to directly measure the velocity of groundwater flow in unconsolidated, saturated, porous media. The flow sensors differ from other devices that measure groundwater velocity in that they are in direct contact with the unconsolidated aquifer matrix where the flow is to be measured, thereby avoiding borehole effects. The flow sensor is a thin, cylindrical device that is permanently buried at the depth where the velocity of groundwater flow is to be measured. The manufacturer claims that the flow meter can measure groundwater flow in the range is 0.01 to 2.0 feet per day (ft/day) (0.3 to 60.96 centimeter per second [cm/s]) with an error of +/- 0.001 feet (0.03 centimeter). Data collected from the flow sensors include the horizontal and vertical groundwater flow rate as well as groundwater flow direction.

The GCW is a patented system manufactured by WEI and was demonstrated at Cape Canaveral Air Station (CCAS) by the U.S. Air Force Center for Environmental Excellence (AFCEE). AFCEE conducted a comprehensive evaluation of the GCW, including contaminant mass removal rates, groundwater dye tracer studies, and numerical modeling. The results of the AFCEE study can be found in the report entitled "Groundwater Circulation Well Technology Evaluation at Facility 1381, Cape Canaveral Air Station, Florida – Final Report" (Parsons, 2001). The results of the EPA SITE Program demonstration provided additional hydraulic data that are useful in characterizing the GCW circulation cell.

AFCEE managed the overall GCW technology evaluation and was responsible for installation, operation, and optimization of the GCW. EPA was responsible for aquifer hydraulic testing and the installation and

acquisition of data from the HydroTechnics flow sensors. Additionally, the Oregon Graduate Institute conducted dye tracer studies and modeling to evaluate the GCW circulation cell.

EPA's evaluation of the HydroTechnics flow sensors was designed with one primary and four secondary objectives to assess the sensor's ability to detect the groundwater circulation cell established by the GCW. The primary and secondary objectives were evaluated by collecting and interpreting data from seven flow sensors, conducting a series of aquifer hydraulic tests, and collecting GCW operational data during four modes of operation. The four modes of operation include: (1) natural flow conditions, (2) circulation conditions, (3) pump-and-treat testing, and (4) aquifer hydraulic testing (step-drawdown, constant-rate pump testing, and dipole flow testing). Data were collected and analyzed using the methods and procedures presented in the Technology Evaluation Plan/Quality Assurance Project Plan (TEP/QAPP) for the project (Tetra Tech 2000). The data from the groundwater flow sensors yielded valuable information regarding the circulation cell of the GCW. The conclusions of the technology evaluation, as they relate to the demonstration project objectives, include:

Primary Conclusions

P1 Evaluate the flow sensor's ability to detect the horizontal extent of the GCW groundwater circulation cell based on a change in the groundwater velocity criterion of 0.1 foot per day (0.03 meter per day)

- During the GCW circulation operation mode, the groundwater velocities measured by all seven sensors increased by more than 0.1 ft/day, indicating that (1) the sensors were within the circulation cell established by the GCW, and (2) the horizontal extent of groundwater circulation was greater than 15 feet. Furthermore, the groundwater flow direction data suggest that groundwater in the upper portion of the treatment zone generally flows radially away from the GCW and that groundwater in the bottom of the treatment zone generally flows radially towards the GCW. This flow direction data further support the establishment of a circulation cell and that all the flow sensors are within the horizontal extent of groundwater circulation cell.

- The data from the four modes of GCW operation suggest that the flow sensors are responsive to changes in groundwater flow conditions and can be used to help define and evaluate the three-dimensional flow pattern created by the GCW. The immediate response of the sensors to changes in GCW operation suggest that the groundwater circulation cell is established within hours instead of days. Additionally, the velocity data from the flow sensors suggest that the GCW circulation flow was generally constant during operation in the circulation mode.

Secondary Conclusions

S1 Evaluate the reproducibility of the groundwater velocity sensor data

- The reproducibility of the sensors during steady state conditions ranged from 0.1 to 23 percent with an average of 1.9 percent and a standard deviation of 3.8 percent.

S2 Evaluate the three-dimensional groundwater flow surrounding the GCW

- Groundwater flow patterns, as measured by the flow sensors, were documented for each of the four GCW operational modes and are depicted graphically to illustrate general flow patterns in the vicinity of the GCW during each mode of operation.

S3 Document the operating parameters of the GCW

- GCW pumping rate, duration of system operation, and GCW shutdowns were documented for each of the four modes of operation:

GCW Operational Mode	Pumping Rate	Duration of Operation	GCW Shutdowns
Circulation	4 gpm	July 10 – 28, 2000	1 shutdown for mechanical maintenance
Pump and Treat	4 gpm	August 2 – 29, 2000	7 shutdowns for mechanical repairs
Aquifer Hydraulic Testing	Various	September 13 – 19, 2000	None
Natural Conditions	No pumping	GCW not operated	GCW not operated

S4 Document the hydrogeologic characteristics at the demonstration site

- Natural groundwater flow velocities at the CCAS Facility 1381 site are very low, ranging from 0.03 to 0.21 ft/day (0.009 to 0.064 meter/day).

- The conductivity of the aquifer at the Facility 1381 site decreased with depth. Based on aquifer hydraulic test data, the hydraulic conductivity ranges from 43 to 53 ft/day (1.5×10^{-4} to 1.9×10^{-4} cm/s) for the shallow zone (upper 7 feet or 2.1 meters) and 5 to 10 ft/day (1.8×10^{-5} to 3.5×10^{-5} cm/s) for the deeper zone (7 to 25 feet deep or 2.1 to 7.6 meters). The Storativity of the lower aquifer zone ranges from 0.006 to 0.007 and specific yield ranges from 0.06 to 0.09. The average anisotropic ratio (that is, the ratio of horizontal to vertical hydraulic conductivity) is 2.4, based on steady-state dipole flow test interpretation.

Additional findings and observations based on the EPA demonstration of the flow sensors include:

- According to the developer, the flow sensors measure flow in a 3.3 cubic feet [1 cubic meter] area volume immediately surrounding the sensor,) and are subject to local heterogeneities. Complex site hydrogeological conditions may require a large number of flow sensors to adequately define the circulation cell and characterize flow patterns.

- To more fully evaluate the three-dimensional flow surrounding this GCW, additional sensors should have been installed at varying distances and depths from the GCW. Flow sensors should be installed at upgradient, downgradient, and cross-gradient locations at a minimum of three different distances from the GCW. The flow sensors also should be installed at three different depths corresponding to shallow and deep GCW screens as well as in the middle portion of the monitored zone between the two screens. The shallow sensors should be installed a minimum of 5 feet (1.5 meters) below the water table, which would minimize the impact of temperature

variations caused by the vadose zone. Only seven sensors were installed for this project because preliminary modeling indicated that the circulation cell would be smaller than what was actually observed in both the upgradient and cross gradient directions.

- HydroTechnics recommends installing the flow sensors with five feet (1.5 meters) of submergence because the shallow portion of the groundwater will heat up during the day, creating a thermal gradient that the sensor measures as water flow. For the EPA demonstration, the shallow sensors were installed with less than 5 feet of submergence because preliminary modeling indicated that there would not be significant flow deeper than 3 feet (1 meter) into the formation. Data from the shallow sensors were successfully corrected by subtracting the background temperature gradient.

- HydroTechnics recommends allowing at minimum of 7 days for the sensors to come to thermal equilibrium. During the EPA demonstration, short-term aquifer tests resulted in large but short-term changes in groundwater flow, that were successfully measured by the flow sensors.

- The cost of a single flow sensor was $2,500. The total cost for the seven sensors, sensor data analysis for a period of 1 year, and installation was $70,000 for this project. Costs at other sites may vary depending on installation depth and subsurface conditions.

1.0 INTRODUCTION

This Technology Evaluation Report (TER) documents and summarizes the findings of an evaluation of HydroTechnics, Inc. in situ flow sensors in measuring the groundwater flow patterns created by an innovative groundwater circulating well (GCW) installed at Facility 1381 at the U.S. Air Force 45th Space Wing, Cape Canaveral Air Station (CCAS), Florida (Figures 1 and 2). The U.S. Environmental Protection Agency (EPA) National Risk Management Research Laboratory (NRMRL) evaluated the using in situ groundwater flow sensors under the Superfund Innovative Technology Evaluation (SITE) Program. The EPA's evaluation was a component of a comprehensive evaluation of the GCW conducted by the U.S. Air Force Center for Environmental Excellence (AFCEE). The flow sensors were evaluated for the SITE Program by measuring the magnitude and direction of groundwater flow near the GCW and by conducting aquifer hydraulic tests using the GCW.

The GCW selected is a patented system manufactured by Wasatch Environmental, Inc. (WEI). AFCEE's support contractor, Parsons Engineering, managed the overall technology evaluation and was responsible for installation, operation, and optimization of the GCW. The EPA SITE Program managed installation and acquisition of data from in situ groundwater velocity sensors and the aquifer hydraulic testing.

This report documents the activities conducted during the demonstration and summarizes data collected by EPA. Demonstration data collected by AFCEE are documented separately and are not included in this report.

The TER is divided into eight sections. Section 1.0 presents the project background, information on the SITE Program, a description of the technology, and key contacts. Section 2.0 describes the environmental setting of the demonstration site and the objectives of the evaluation, methods and procedures, and modifications to the Technology Evaluation Plan/Quality Assurance Project Plan (TEP/QAPP) (Tetra Tech 2000). Section 3.0 describes the groundwater circulation system, and Section 4.0 describes the groundwater flow sensors. Section 5.0 presents interpretation of data from the groundwater flow sensors used during the evaluation. Section 6.0 presents the results of the technology evaluation, while Section 7.0 presents the conclusions of the evaluation. References are included in Section 8.0.

1.1 PROJECT BACKGROUND

As part of ongoing efforts to address impacts to groundwater from chlorinated solvents, CCAS is conducting a series of pilot-scale treatability studies to obtain site-specific data on performance and cost for potentially applicable remediation technologies. AFCEE identified the WEI GCW as a possible solution for remediation of nonaqueous-phase liquids (NAPL) source areas such as Facility 1381. Facility 1381 was selected as the demonstration site because it was thought to have a favorable site hydrogeologic condition (relatively high hydraulic conductivity) and the presence of a NAPL source.

GCW technologies have been proposed as a cost-effective alternative to traditional pump-and-treat technologies for remediation of groundwater contaminated with volatile organic compounds (VOC). AFCEE developed a comprehensive test plan to evaluate the GCW, which included installation of a 6-inch GCW and 99 microwells that radiate from the GCW; collection of samples from the soil core, groundwater, and air for subsequent geotechnical and chemical analysis; completion of a dye tracer test; and development of a site groundwater flow model. AFCEE alternated operation of the GCW between pump-and-treat mode and circulation mode to obtain reliable data on the relative capabilities of the GCW technology. Samples of groundwater and air were collected during both modes of operation to obtain performance data under various operating scenarios and to allow comparisons of results.

AFCEE invited EPA to participate in an evaluation of a GCW at CCAS Facility 1381. To evaluate the circulation cell, EPA installed in situ groundwater flow sensors to measure the magnitude and direction of groundwater flow near the GCW, and conducted a series of aquifer hydraulic tests. Data from the groundwater flow sensors were collected during (1) long-term pump-and-treat operation, (2) long-term GCW operation, (3) final pump-and-treat operation, (4) aquifer hydraulic tests, and (5) post-GCW operation.

A summary of the various operational periods is provided bebw.

Long-Term Pump-and-Treat Operation. The GCW was installed at the site in November 1999. After a tidal influence study, tracer test, and a series of short-term aquifer hydraulic tests, the system began operation in pump-and-treat mode in February 2000. The system remained in pump-and-treat mode through April 2000. AFCEE monitored the system to calculate mass removal rates for comparison to rates achieved during other modes of operation by the GCW.

Long-Term GCW Operation. Long-term operation of the GCW was initiated in April and continued until July 2000. The in situ groundwater flow sensors were installed in June 2000. Continuous collection of data on groundwater flow from the sensors was initiated in July 2000.

Final Pump-and-Treat Operation. Final pump-and-treat operation of the GCW was conducted during August 2000. Eight transducers were installed to evaluate changes in hydraulic head in the aquifer during August 2000.

Aquifer Hydraulic Test Operation. A series of aquifer hydraulic tests were conducted in September 2000. Hydraulic head data were collected from the aquifer using eight pressure transducers, and data on direction and magnitude of groundwater flow were collected from the seven in situ groundwater flow sensors.

Post-GCW Operation. The GCW has not operated after aquifer hydraulic testing was completed in September 2001. EPA collected data from the in situ groundwater flow sensors from September 2000 through September 2001 to document groundwater flow during non-operation of the GCW.

1.2 DESCRIPTION OF FLOW SENSOR AND GCW TECHNOLOGIES

The groundwater flow sensors installed at CCAS were developed at Sandia National Laboratories and manufactured by HydroTechnics, both of Albuquerque, New Mexico. The flow sensors are in situ instruments that use a thermal perturbation technique to directly measure the velocity of groundwater flow in unconsolidated, saturated, porous media. The flow sensors differ from other devices to measure groundwater velocity in that they are in direct contact with the unconsolidated aquifer matrix where the flow is to be measured, thereby avoiding borehole effects. The flow sensor is a thin, cylindrical device that is permanently buried at the depth where the velocity of groundwater flow is to be measured.

The WEI GCW is an in situ groundwater remediation system designed to circulate groundwater in the aquifer and strip VOCs. In the WEI system, airlift pumping lifts groundwater from a screen in the lower section of the well. Air is pumped to the bottom of the well by a blower, reducing the weight of the water column. Groundwater and air are then lifted to an upper screen, where the air strips VOCs and the groundwater is allowed to discharge back into the aquifer. The air stream used to strip VOCs is extracted from the wellhead and is treated before it is released to the atmosphere. Groundwater that reenters the

aquifer through the top screen flows vertically downward and can be recaptured by the GCW, so that it can be treated again. The three-dimensional groundwater flow regime developed by the GCW is termed a "circulation cell," and its characteristics are critical to the effectiveness of the technology. Key parameters of the circulation cell are its size, or radius, and its percent capture (Parsons 1999a).

1.3 THE SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION PROGRAM

EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) created the SITE Program in response to the Superfund Amendments and Reauthorization Act of 1986 (SARA). The SITE Program promotes the development, evaluation, and use of new or innovative technologies to clean up Superfund sites across the country.

The primary purpose of the SITE Program is to maximize the use of alternatives in cleaning up hazardous waste sites by encouraging development and evaluation of innovative treatment and monitoring technologies. It consists of three major elements:

- The Technology Evaluation Program
- The Monitoring and Measurement Technologies Program
- The Technology Transfer Program

The objective of the Technology Evaluation Program is to develop reliable data on performance and cost for innovative technologies so that potential users may assess the technology's site-specific applicability. Technologies evaluated are either currently available or are close to being available for remediation of Superfund sites. SITE evaluations are conducted on hazardous waste sites under circumstances that closely simulate full-scale remediation conditions, thus ensuring the usefulness and reliability of the information collected.

Existing technologies that improve field monitoring and site characterizations are identified in the Monitoring and Measurement Technologies Program. This program supports new technologies that provide faster, more cost-effective contamination and site assessment data. The Monitoring and Measurement Technologies Program also formulates protocols and standard operating procedures for evaluation methods and equipment.

The Technology Transfer Program disseminates technical information on innovative technologies in the Evaluation and Monitoring and Measurements Technologies Programs through various activities. These activities increase the awareness and promote the use of innovative technologies for assessment and remediation at Superfund sites. The goal of the technology transfer is to develop communication among individuals who require up-to-date technical information.

1.4 KEY CONTACTS

Additional information on the SITE Program and the evaluation can be obtained from the EPA Project Manager:

> Michelle Simon
> U.S. Environmental Protection Agency
> Office of Research and Development
> 26 West Martin Luther King Drive
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> Telephone: (513) 569-7469, Facsimile: (513) 569-7676
> E-mail: simon.michelle@epa.gov

Additional information on AFCEE's evaluation of the GCW technology can be obtained from the AFCEE project manager:

> James Gonzales
> Air Force Center for Environmental Excellence
> 3207 North Road
> Brooks AFB, Texas 78235-5363
> Telephone: (210) 536-4324, Facsimile: (210) 536-4330
> E-mail: james.gonzales@hqafcee.brooks.af.mil

Additional information on the WEI GCW technology or the evaluation can be obtained from the technology vendor:

> Tabor DeHart
> Wasatch Environmental, Inc.
> 2410 West California Avenue
> Salt Lake City, Utah 84104
> Telephone: (801) 972-8400, Facsimile: (801) 972-8459
> E-mail: wasatchenv@aol.com

Additional information on in situ flow sensors or this evaluation can be obtained from:

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In addition, information on the SITE Program is available through the following on-line information clearinghouses:

- SITE Program Home Page: http://www.epa.gov/ORD/SITE. All recent SITE reports, including this one can be downloaded from this web site.
- The Alternative Treatment Technology Information Center (ATTIC) Internet Access: http://www.epa.gov/attic
- Cleanup Information Bulletin Board System (CLU-IN)
  Help Desk: (301) 589-8368; Internet Access: http://www.clu-in.org
- EPA Remediation and Characterization Innovative Technologies
  Internet Access: http://www.epa.reachit.org
- Groundwater Remediation Technology Center
  Internet Access: http://www.gwrtac.org

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